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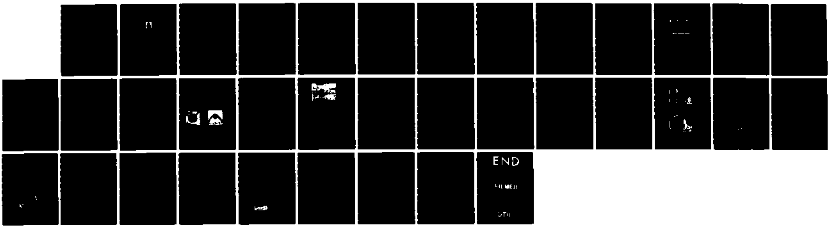

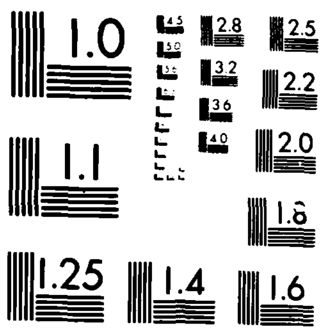

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ELECTROMAGNETIC PULSE - THE FIFTH FACTOR IN THE IMPACT
OF A NUCLEAR EXPLOSION

by

Z. Jastak

FOREIGN TECHNOLOGY DIVISION

FTD-ID(RS)T-1176-85

EDITED TRANSLATION

FTD-ID(RS)T-1176-85 16 January 1986

MICROFICHE NR: FTD-86-C-001361

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By: Z. Jastak

English pages: 29

Source: Przeglad Wojsk Ladowych, Nr. 7, July 1971, pp. 100-119

Country of origin: Poland
Translated by: SCITRAN
F33657-84-D-0165
Requester: FTD/TQTD
Approved for public release; distribution unlimited.

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ELECTROMAGNETIC PULSE-THE FIFTH FACTOR IN THE IMPACT OF A NUCLEAR EXPLOSION

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Words translated: 5488

Pages translated: 20 pages

Date translated: January, 1986

FTD I.D. No.: FTD-ID(RS)T-1176-85

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Santa Barbara, California 93108
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ELECTROMAGNETIC PULSE - THE FIFTH FACTOR IN THE IMPACT OF A NUCLEAR EXPLOSION.

Colonel Zbigniew Jastak

A small nuclear charge releases an enormous amount of intranuclear energy in the form of kinetic energy, excitation energy and neutron energy as well as gamma radiation within several millionths of a second. This generates the enormous destructive power and impact action of a nuclear explosion.

Shock waves, thermal and penetrating radiations as well as radioactive contamination of terrain and buildings occur while the physical phenomena which accompany a nuclear explosion develop.

There are electromagnetic fields in addition to the known impact factors. These electromagnetic fields generate pulses and voltages in overhead and underground conductors, power lines and telecommunication cables as well as in radio station and television antennas, among other things. These pulses and voltages can damage component parts in radio, television and radar devices as well as interfere with the operation of command and information systems and electric power plants. Finally, they can also give people electric shocks.

* * *

A fission chain reaction initiates the process of any nuclear explosion. Neutrons and gamma radiation are released from the explosion zone into the surrounding medium during this reaction. Their flux constitutes a part of **penetrating radiation in nuclear explosion.**

Gamma radiation and atoms which are present in the surrounding medium interact with each other and form a fast electron flux which moves at a high speed in different directions from the explosion center as well as stationary positive ions. This is how positive and negative charges are divided in space. In turn, this division generates electric and magnetic fields. These fields are called the **electromagnetic pulse of a nuclear explosion** due to their short duration. The magnitude, direction and shape of these fields depend on the power of the nuclear explosion, how the nuclear weapon is built as well as on how dense the surrounding medium is. (The electromagnetic phenomena which occur during a nuclear explosion will be discussed in detail later in this article).

The pressure reaches tens of millions of kilograms per square centimeter, while the temperature climbs to tens of millions of degrees in the zone of the nuclear reaction during a few millionths of a second. This results from the release of an enormous quantity of energy in a very small volume. Under these conditions, energy is transferred rapidly to the substance surrounding the reaction zone. The substance is heated to tens of millions of degrees. The substance used in making nuclear weapons evaporates when exposed to this high temperature, emitting an intense electromagnetic radiation flux. Most of this radiation is identical to the Roentgen band of the spectrum. X-ray radiation is absorbed by the surrounding atmosphere and heats it. A luminous zone containing hot air and gases generated within the explosion zone results from this absorption and heating. The luminous zone is a source of **thermal radiation in nuclear explosion**.

A spherical mass of incandescent air expands rapidly. Vapors and gases, including air, are heated to an extremely high temperature. Similarly to all incandescent bodies, they retain the property of being able to illuminate and form a luminous zone. This luminous zone is called **the fire ball of the explosion**. The fireball's surface is many times brighter than that of the sun at the initial stage. This is why a nuclear explosion is accompanied by a blinding flash.

The enormous energy generated by the nuclear reaction is released into a limited space which is occupied by the nuclear charge. The total quantity of elementary particles increases by 200 times. An enormously high temperature is created in the reaction zone, and the pressure climbs to the millions of atmospheres. (The maximum pressure reaches "only" 200,000 atmospheres during a trinitrotoluene explosion).

The difference between the pressure existing in the explosion zone and that in the surrounding atmosphere causes the vapors and gases heated to a high temperature to expand. While expanding, the vapors and gases compress and shift the surrounding atmosphere. This atmospheric compression and shifting occurs at a supersonic speed in all directions from the explosion's center. This is how so- called **shock wave of the nuclear explosion** phenomenon occurs. This phenomenon is similar to the wave generated during the explosion of conventional explosives.

The pressure is highest at the leading edge of shock wave, the so-called shock front. The shock front shifts rapidly towards the outside of the fireball and forms a "movable wall" of strongly condensed air called the overpressure area. The overpressure decreases along and behind the shock front as the shock wave moves away from its source. The pressure dips below the atmospheric pressure at a certain distance behind the shock front, and an underpressure zone forms.

The initial atmospheric compression is so great that the temperature along the shock front increases to thousands of degrees. The shock front emits strong fluxes of thermal radiation as a result of this high temperature. Therefore, the shock front makes up the surface of the fireball. At that time, the shock front does not permit the radiation to get out from inside of the fireball. The fireball consists of incandescent vapors and gases.

The pressure and atmospheric temperature along the shock front decreases as the area encompassed by the shock wave increases. The area expands very rapidly. When the temperature drops to approximately 2000°C, the shock front stops illuminating and becomes transparent. The inside of the fireball is visible beginning at this moment. Vapors and gases heated to a high temperature form the fireball. The inside of the fireball has a much higher temperature than does the atmosphere along the front.

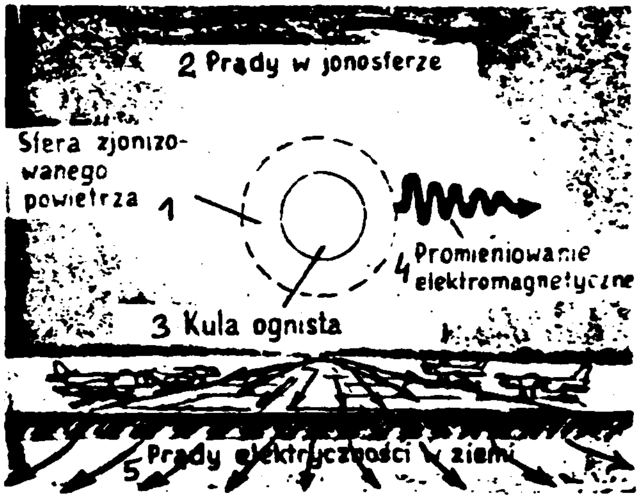
Therefore, the inside of the fireball becomes a source of thermal radiation when the shock front stops illuminating.

The minimum intensity level of the fireball's luminosity may be distinguished as it is developing (i.e., the period between the first and second phase of the fireball's development). The first phase lasts approximately 0.01 to 0.02 seconds during a medium-sized nuclear explosion. The shock front moves approximately 100 meters away from the explosion center by the end of the first phase.

In the first phase, the rate at which the inside of the fireball expands is equal to the speed at which the shock front moves. Subsequently, this rate decreases and the shock front breaks away from the inside of the fireball and moves towards the front. The moment at which the shock front breaks away happens at about the same time as minimum illumination intensity occurs. This marks the end of the first phase in the fireball's development.

The volume and dimensions of the fireball continue to increase in the second stage of development. Its surface temperature increases rapidly to 8000°C and then decreases.

The fireball is much larger in the second phase than in the first phase, and its illumination time is much longer. Approximately 98% of the entire thermal radiation energy in a nuclear explosion radiates in the second phase.



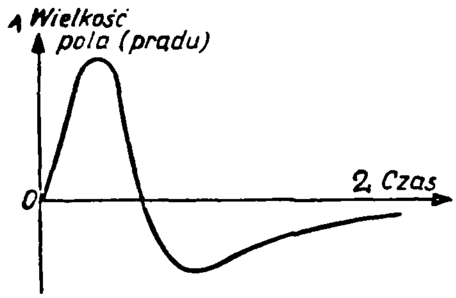
Picture 1. The formation of electromagnetic fields as well as atmospheric and ground currents resulting from the formation of the fireball in the explosion zone and the large zone of ionized air.
1. Zone of ionized air. 2. Ionospheric currents. 3. Fireball.
4. Electromagnetic radiation. 5. Ground electric currents.

Electromagnetic fields and currents are generated in the air and on the ground by the formation of the fireball and the large zone of ionized air in the explosion zone. The large ionized air zone occurs due to penetrating radiation (picture 1). The excitation currents and voltages are brief pulses lasting several milliseconds (picture 2), and are similar to pulses which occur during statics.

The radius of the fireball reaches approximately 300 meters three seconds after the explosion. The shock front moves approximately 1600 meters away from the explosion center.

Energy is consumed to heat the air and is released into the surrounding atmosphere. The fireball becomes much larger. Due to the above-mentioned factors, the temperature on the surface of the fireball (i.e., the intensity with which the thermal energy radiates) decreases. The fireball changes into a radioactive cloud in a nuclear explosion.

Radioactive products contained in the fireball are in the form of vapors and gases, and assume the form of hard radioactive substances having different sizes. These substances are suspended in the cloud which forms after the explosion. The cloud contains water vapor and atmospheric dust in addition to the products which stem from the explosion. The cloud also contains dust which is forced into the air during ground and low-air explosions (due to atmospheric currents and being drawn into the cloud).



Picture 2. Excitation currents and voltages are brief pulses.
1. Magnitude of the field (current). 2. Time.

The dust which is pulled into the cloud contains radioactive substances which formed in the ground while exposed to neutrons. The soil itself becomes radioactive from exposure to neutrons only near the ground-zero point. This radioactivity is called induced radioactivity, and its activity (which is dependent on artificial radioactive isotopes) is called induced activity.

The cloud is less dense than the surrounding atmosphere. The cloud therefore lifts upwards, similarly to a balloon filled with gas which is lighter than air. At the same time, horizontal atmospheric currents (winds) make it drift, moving it in the direction in which they are blowing.

Some of the radioactive products in the cloud cool and mix with melted surface layers of the soil which were lifted up into the atmosphere. Other radioactive products cling to the dust particles and drops of condensing water vapor. Gravity forces the radioactive substances contained in particles of soil, dust and water to precipitates to the earth's surface. They fall in the area in which the explosion took place and along the path on which the cloud moved. The radioactive substances cause **radioactive contamination of the terrain and objects on it.**

The following are therefore generated during a nuclear explosion: **A powerful shock wave**, intensive **thermal and penetrating radiation, radioactive contamination of the terrain and objects on it as well as an electromagnetic pulse**. These are the so called **factors involved in the impact of a nuclear explosion**.

* * *

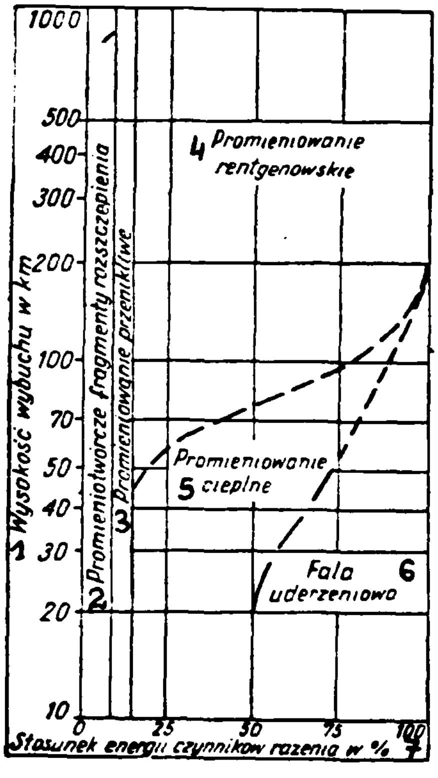
The factors involved in the impact of a nuclear explosion differ from one another not only by the characteristics of their influence, but also by the fact that they come into play at various times. Penetrating radiation, electromagnetic pulse and thermal radiation set in earlier than any other factors at the moment of the explosion. Generally, penetrating radiation lasts from several seconds (during the smallest-, small- and medium-yield blasts) to 15 to 25 seconds (in high-yield blasts). The electromagnetic pulse lasts several fractions of a second, while thermal radiation lasts from fractions of a second to several dozen seconds, depending on the yield of the blast.

The shock wave starts to affect an object after a certain period of time. This period of time depends on the blast yield and how far the object moves from the ground-zero point. The shock wave propagates at an average velocity slightly higher than the speed of sound. The shock wave lasts from fractions of a second (in small-yield explosions) to several seconds (in high-yield blasts).

The terrain and objects on it become radioactively contaminated much later (i.e., after the remaining factors are no longer active). Radioactive dust can contaminate the terrain and objects on it which lie beyond the reach of the shock wave, thermal radiation and penetrating radiation as well as the electromagnetic pulse. When radioactive fallout occurs immediately after the explosion depends on the kind and yield of the blast, distance from the blast center as well as on the wind speed. This time ranges from several minutes to several hours.

Radioactive contamination lingers for several hours, days or even weeks, unlike other impact factors which affect the terrain and objects on it for several and several dozens of seconds after the blast within a radius of several kilometers. Radioactive contamination reaches regions located several hundreds of kilometers from the blast. Radioactive substances contaminate not only the terrain, but also military equipment, water reservoirs, crops, buildings and other objects which are located along the path of the radioactive cloud.

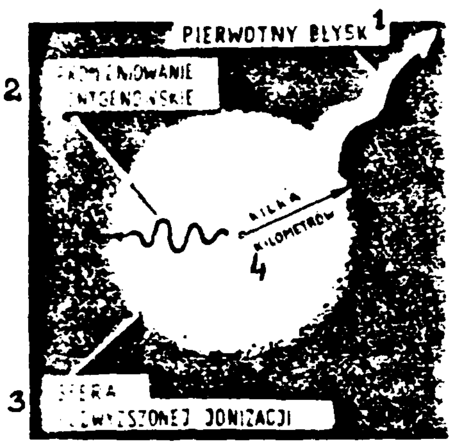
As the altitude of the nuclear blast increases, the quantity of energy in the shock wave and thermal radiation decreases. At the same time, the energy carried from the explosion zone by X-ray radiation and disintegrating products of the explosion (picture 3) decreases. The amount of energy in penetrating radiation is equal at all altitudes. The higher the explosion, however, the larger the radius of its impact. There is no radioactive contamination of the terrain during high-altitude nuclear explosions and explosions carried out at even greater distances from the earth.



1. Explosion height in km.
2. Radioactive fragments from fission.
3. Penetrating radiation.
4. X-ray radiation.
5. Thermal radiation.
6. Shock wave.
7. Energy ratio of impact factors (%).

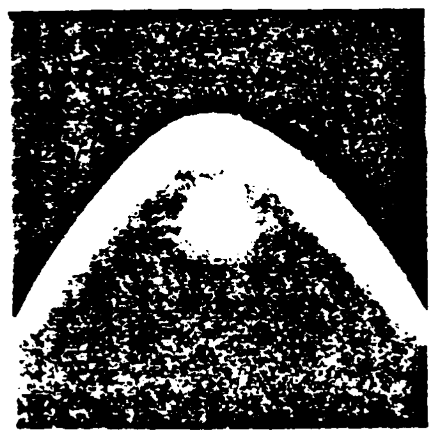
Picture 3. Energy of each factor of impact during a high-altitude nuclear explosion.

A brief flash (picture 4) is caused by the luminescence of products from the blast during a high-altitude nuclear explosion in rarefied atmosphere. Even people who are far away from the center of the blast might be blinded by the flash. The ionized products and air which was ionized due to X-ray radiation form an area of elevated ionization. The disintegrating products from the explosion are slowed down by the rarefied air within a zone spanning tens of kilometers, which results in the shock wave. The air at the leading edge of the shock wave illuminates because it is intensely heated and ionized. Because the atmosphere has different densities at various altitudes, the luminescent leading edge of the shock wave is initially elliptical (picture 5), later becoming bowl-shaped.



Picture 4

A brief flash generated during a high-altitude nuclear blast.



Picture 5

The luminous front of the shock wave.

1. Initial flash. 2. X-ray radiation. 3. Increased ionization zone. 4. Several kilometers.

Three ionization zones form during high-altitude nuclear explosions (picture 6).

1) A short-lived ionization zone in the area of the nuclear explosion;

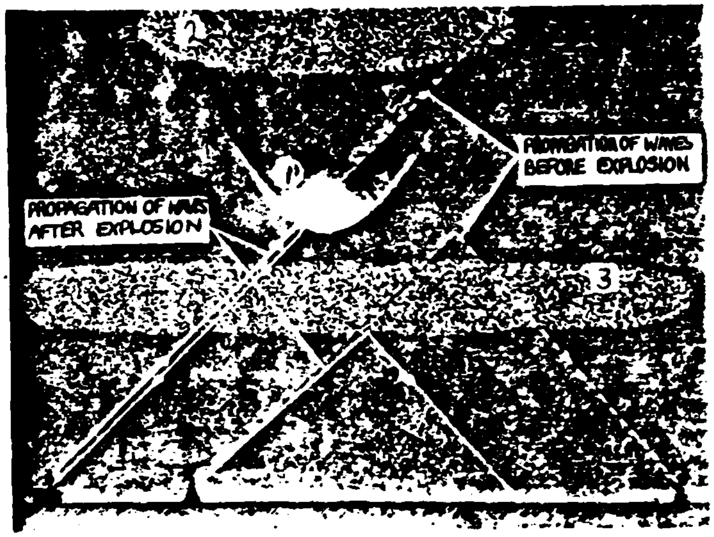
2) Radioactive cloud hovering over the center of the explosion. The cloud consists of ionized volatile products from the explosion and lingers for several hours or even days;

3) A large zone of increased ionization resulting from gamma and X-ray radiation as well as from neutrons. The zone forms at an altitude of 40 to 70 kilometers and remains for several days.

Increased ionization zones have an impact on radio wave propagation and interfere with radio communication as well as the operation of radar stations.

Radiation emitted from the increased ionization zone can have an impact on changing the parameters of elements in electronic devices, especially semiconductors. This can in turn interfere with the operation of other equipment, including radio stations, radars, and infrared telescopes, and can also damage this equipment.

The four factors involved in the impact of a nuclear explosion (shock wave, thermal and penetrating radiations as well as radioactive contamination) are generally well-known. However, the fifth factor, electromagnetic phenomena (electromagnetic pulse), is less known.



Picture 6. Ionization zones generated during a high-altitude nuclear explosion.
1. Short-lived ionization zone. 2. Radioactive cloud consisting of ionized, volatile products from the explosion. 3. Large zone of increased ionization at an altitude of 40 to 70 kilometers.

FORMATION OF AN ELECTROMAGNETIC PULSE

An enormous quantity of gamma and neutron quanta is emitted during a nuclear explosion. Some is absorbed by the coating of nuclear weapon, while the remainder drifts into space. Gamma quanta and neutrons as well as atoms in the medium interact with each other in space.

When gamma quanta and atoms in the medium interact, an energy pulse is transferred to them. A fraction of this energy is used to ionize atoms. Most of it is used for the translatory motion of electrons and ions generated by ionization. Electrons have a greater velocity than ions because more energy is transferred to electrons than to ions and because there is a substantial difference in mass between the two groups. One can assume that ions are stationary and that electrons move away from them at a speed approaching that of light. These electrons are called **primary** electrons. Primary (fast) electrons follow the pattern of the radii (i.e., move from the center of the explosion outward) and form currents and electric fields which increase with the passage of time.

Fast electrons have a high energy and continue to ionize the medium. Each of these electrons can generate up to 30,000 secondary (slow) electrons and positive ions. The secondary electrons start to move towards the center of the explosion (i.e., in the opposite direction of the fast electrons) due to the effect of the electric field which is generated by primary electrons and ions. Along with secondary positive ions, secondary electrons generate fields and electric currents which compensate primary fields and electric currents.

The velocity of primary electrons is several times that of the secondary electrons. The compensation process of primary fields and electric currents therefore lasts much longer than the process of their formation. As a result of these processes, short-lived electric and magnetic fields form in the air. These fields constitute the electromagnetic pulse of a nuclear explosion.

The neutrons which penetrated the coating of a nuclear weapon are captured by nitrogen atoms, and at the same time emit the gamma radiation which they carried with them. The radiation and atoms interact with the atoms present in the medium, similarly to the gamma radiation which is a part of the penetrating radiation. This radiation can maintain fields and electric currents and lasts several fractions of a second after the explosion. It is therefore one of the major factors determining how long the electromagnetic phenomena which accompany the nuclear explosion last.

The processes of interaction between gamma quanta, neutrons and fast electrons as well as atoms present in the medium do not proceed uniformly in all directions. There are always directions in which gamma quanta and other particles mentioned propagate less energetically or take up less space. This can result from a number of factors, including the asymmetry in the design of a nuclear weapon, the nonuniform atmospheric density in the area surrounding the nuclear weapon, the earth's surface along the path on which gamma radiation and neutrons propagate and the impact on the direction in which electrons from electric and magnetic fields on the ground move. Because of the reasons enumerated above, electromagnetic fields lose spherical symmetry and acquire a specific direction. For example, an electric field generated on the surface of the earth is directed horizontally in most cases during a ground explosion.

Other factors which contribute to the formation of an electromagnetic pulse in a nuclear explosion include the radiation of gamma fragments, electric phenomena generated by heating the earth at the ground-zero point, and the direct electrification of the earth, metal objects, wires, and cables by irradiating them with a neutron flux and gamma quanta. Depending on the conditions under which a nuclear explosion takes place, each process contributes differently to the generation of an electromagnetic pulse. Its parameters also change because of this.

THE MAIN PARAMETERS OF AN ELECTROMAGNETIC PULSE

The major parameters of an electromagnetic pulse are the nature of the changes which occur in the intensity of electric and magnetic fields (the form which the pulse assumes) over time and the magnitude of the maximum field intensity (the pulse amplitude). These parameters determine the impact of the electromagnetic pulse.

The electromagnetic pulse is a single signal having a steep front during a ground nuclear explosion several kilometers from the center of the explosion. It lasts for a split second. The energy of the electromagnetic pulse has a wide frequency range (from dozens of hertz to several megahertz). The band of the spectrum having the highest frequency contains a small amount of pulse energy, however. Most of this spectral band is within the 30 kilohertz frequency range.

The amplitude of the electromagnetic pulse within a given zone can reach very high magnitudes. In the atmosphere, these magnitudes may total tens of thousands of volts per meter during powerful nuclear explosions. At the same time, the amplitude of an electromagnetic pulse can reach hundreds and thousands of volts per meter in the ground.

Because the amplitude of an electromagnetic pulse decreases rapidly as distance increases, the pulse of a ground nuclear explosion is an impact factor which comes into play several kilometers from the explosion center. This factor can lead to short-lived interferences in the operation of radio engineering devices at great distances.

During a low-altitude nuclear explosion, the parameters of an electromagnetic pulse are generally the same as they are during a ground explosion. The pulse amplitude diminishes when the explosion takes place at a higher altitude, however.

The amplitude of an electromagnetic pulse is much smaller during underground and underwater explosions than it is during an atmospheric explosion. Its impact is therefore virtually disregarded.

Fast electrons are generated during high-altitude nuclear explosions by the interaction between gamma quanta and atoms present in the coating of the weapon and the surrounding medium (as happens during atmospheric nuclear explosions). The length of the free path for electrons can reach hundreds and thousands of meters in low-density atmosphere, depending on the altitude of the explosion. The motion of fast electrons is not rectilinear, but spiral (along the lines of forces present in the geomagnetic field) due to the influence of the earth's magnetic field. Some of the kinetic energy of the electron is used for electromagnetic radiation within the range of radio waves. The velocity of fast electrons decreases due to partial energy loss.

The electromagnetic radiation of electrons which move in the earth's magnetic field is called magnetic decelerating radiation*. During a high-altitude nuclear explosion, the magnetic radiation which decelerates fast electrons appears near

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* Electromagnetic radiation generated when the path of a charged particle deflects under the influence of a magnetic field.

the earth's surface as a single electromagnetic pulse having a steep front and lasts for several microseconds.

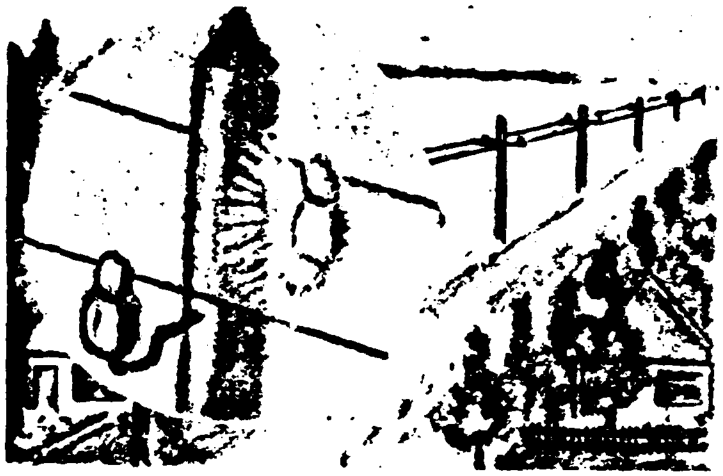
The amplitude of the electromagnetic pulse depends on the altitude of the explosion. The amplitude can reach several hundred thousand volts per meter hundreds of kilometers from the ground-zero point.

THE IMPACT OF AN ELECTROMAGNETIC PULSE

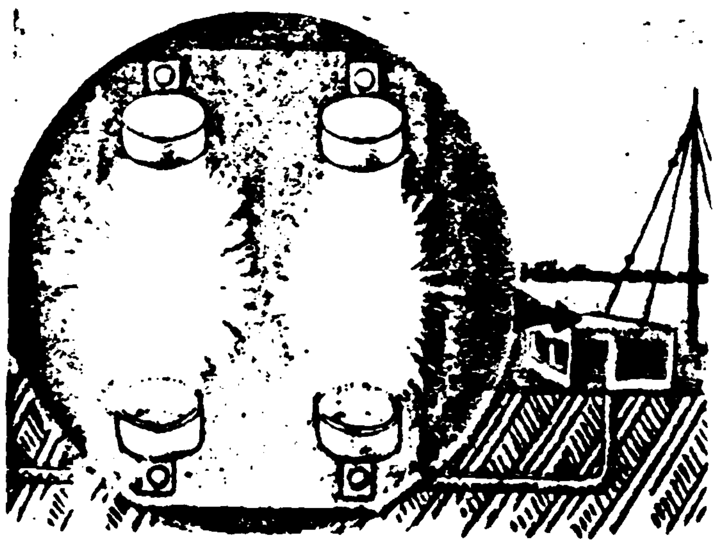
Overvoltage (a short, sudden increase of voltage in a power network above the permissible value) is generated as a result of the impact which the electromagnetic pulse has on wire lines and cables. This creates the danger that **over-currents** (an excessive increase in the intensity of current flowing in an electric circuit) will occur.

Overvoltages reach the highest value during ground explosions and low-altitude atmospheric explosions. The electromagnetic pulse does not have an impact during underground (underwater) and high-altitude atmospheric explosions.

Overvoltage occurring in telecommunication lines and heavy current lines can puncture the insulation of electric equipment (wires, cables, transformers and spark gaps). This can happen during ground and low-altitude nuclear explosions within a zone having a radius of several kilometers from the ground-zero point. The overvoltage can also damage or destroy insulators in electronic and radio engineering equipment (picture 7), components in devices (including semiconductors, resistors and condensers) and overheat safety devices (picture 8) and fuse-links which are connected to lines as **devices protecting against** overvoltage.



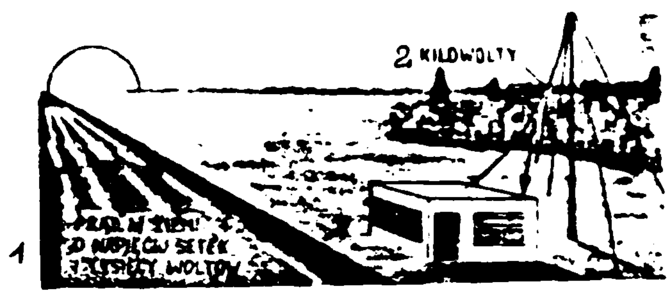
Picture 7. Impact of overvoltage on insulators.



Picture 8. Safety devices got burnt due to the overvoltage.

The over-current in turn creates the threat that superheating will occur, and therefore that incombustible parts will melt and combustible parts will catch fire (i.e., insulation) in elements which conduct over-current as well as in neighboring elements. The over-current poses the threat that mechanical damages will occur as a result of the dynamic impact large currents will have.

Overvoltages generated between the ducts of double circuit overhead lines and between the ducts and the earth reach tens or even several hundred thousand volts during ground nuclear explosions and explosions within a radius of several kilometers from the ground-zero point. An overvoltage can reach a magnitude of tens of thousands of volts between the conductor of underground cables and the earth's surface (picture 9). Overvoltages between the earth and ducts (cables) of lines are tens or several hundred times higher than overvoltages between the ducts (cables) themselves.



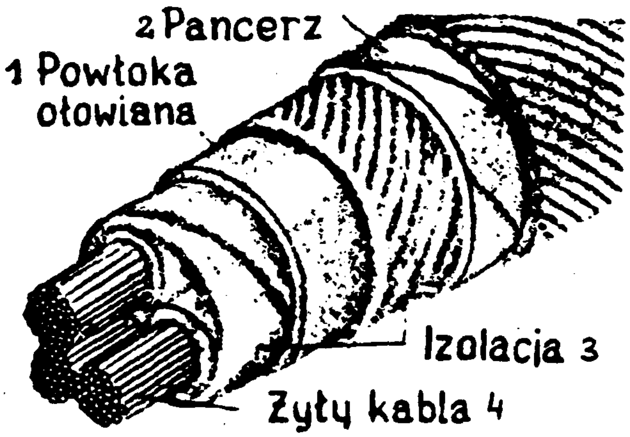
Picture 9. Overvoltage between the conductors of underground cables and the earth's surface during ground and atmospheric nuclear explosions.
1. Current in earth having a voltage of hundreds and thousands of volts. 2. Kilovolts.

Telecommunication systems are more vulnerable than other systems to the impact which the electromagnetic pulse has during a nuclear explosion. Ducts, cables and devices used in these kinds of systems have an electric strength to the impact of direct current which measures up to approximately 4 kilovolts. The electromagnetic pulse of a nuclear explosion lasts for a very short period of time, however. Taking this into consideration, it is possible to accept a slightly higher average electric strength (up to approximately 10 kilovolts when no protective means are used). If even general protective equipment against overvoltages generated during statics were used in lines and devices, the magnitude of overvoltage would even amount to 50 kilovolts. This equipment is itself exposed to overvoltages, and at the same time protects the shielded devices from overvoltages.

It is necessary to bear in mind, however, that even if the magnitude of the electromagnetic pulse is too small to destroy the apparatus, the pulse is strong enough to destroy all the protective devices (including lightning arresters and fuse-links). At the same time, the pulse can interfere with the operation of a line for the period of time which is necessary to repair the line, to replace the protective devices and so forth.

Heavy current lines and devices for conducting this current are mostly designed to carry electric energy having a voltage of tens and hundreds of kilovolts. This is why they are more resistant to an electromagnetic pulse during a nuclear explosion than lines and telecommunication devices.

The electromagnetic pulse does the most damage to devices located in permanent fortification devices which are resistant to the impact of a shock wave arising from a nuclear bomb exploded near the device. Electromagnetic pulse can damage unprotected communication devices in this equipment. Almost all communication lines which are connected to the fortification device will be damaged due to overvoltage. Communication will be interrupted for the period necessary to repair the device. Overvoltages occurring between the duct and the earth reach the highest magnitude. This is why the outer communication lines should be double circuit lines and be well insulated from the earth. The ducts should have the same electric capacity as the earth, and the underground cables should have metal shields which lower the voltage between the cable and the earth several times over (picture 10).



Picture 10. Metal shields in cables reduce the voltage between the cable and the earth.
1. Lead coating. 2. Shield. 4. Insulation. 4. Cable conductors.

Overvoltage pulses reach a magnitude of several hundred to several thousand volts in overhead heavy current lines during high-altitude nuclear explosions. Their magnitude can be so great that protective equipment will be destroyed and the operation of the line will be interrupted. The overvoltage can even occur several hundred kilometers away from the ground-zero point of the explosion.

Overvoltages occurring during nuclear explosions can strike soldiers operating communication devices. Table 1 lists the possible effects from alternating current having a 50 Hz frequency as it passes through a human body.

Table 1.
The effect which alternating current having a 50 Hz frequency has while passing through a human body when a person touches a duct.

Current intensity	Symptoms
up to 0.8 mA	The current virtually unnoticed.
4 to 5 mA	Pain is felt, contractions occur in hands.
5 to 5.5 mA	Contractions reach the arm.
11 to 12 mA	Contractions reach the back.
13 to 14 mA	Difficulty in removing hand from duct.
15 mA	Victim cannot remove hand from the duct without assistance.
20 mA	Possible death (by electrocution).

If the heart lies on the path along which the current flows (i.e., the hand-hand or hand-leg path), the current intensity which trigger death is 0.075 to 1 A, due to the so-called fibrillation (systoles and diastoles) of the heart chambers. When frequencies are higher, the intensity range capable of electrocution shifts towards larger currents.

The intensity of the current passing through the body depends on the body's resistance and on the magnitude of intensity. The resistance of a human body depends primarily on the condition of the skin through which the current enters the body. Human resistance is approximately 1000 ohms (disregarding the resistance when the current goes through the skin).

The degree to which the current has an impact on a human being depends on the following factors: The value of impact intensity, the duration of the current flow, moistness of the skin, the physical condition of the person exposed to the current, his psychological condition and his preparedness for such an occurrence.

PROTECTION AGAINST THE IMPACT OF AN ELECTROMAGNETIC PULSE

If protective measures are taken, the impact which the electromagnetic pulse has on outside and inside lines decreases markedly.

The protective equipment and methods against the impact of an electromagnetic pulse are the same for all kinds of nuclear explosions. Protective and safety devices are connected to each point on the heavy current system and also on those points where receivers are installed. These devices have the following objectives:

- to protect the personnel operating electric devices against electrocution (artificially increasing the resistance of the human body by using additional insulating material);
- to protect electric devices against damage by preventing

dangerous voltages from occurring in the metal parts of the casing around electric devices and by switching the voltage off immediately when a hazardous voltage (overvoltage) occurs on the metal parts of its casing;

- to take protective measures against fires which can occur due to the damages inflicted on electric devices;
- to control the continuous supply of electric energy to receivers despite possible interferences;

The following devices should be used while protecting devices connected to the line against the electromagnetic pulse during a nuclear explosion:

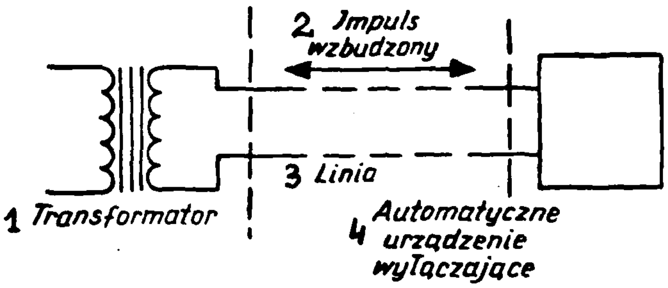
- double circuit symmetrical lines;
- shielded cables or cables put into metal pipes;
- anti-static devices;
- protective equipment.

Double circuit symmetrical lines. *The magnitude of the* voltage between ducts in these lines is determined primarily by differences in the capacity of each duct (asymmetrical capacitance) relative to the earth. Line balancing based on capacity makes it possible to reduce the difference in voltage between the ducts as compared to the voltage relative to the earth by tens or even several hundred times. One has to bear in mind, however, that the voltage relative to the earth in a double circuit line will be the same as it is in a single circuit line.

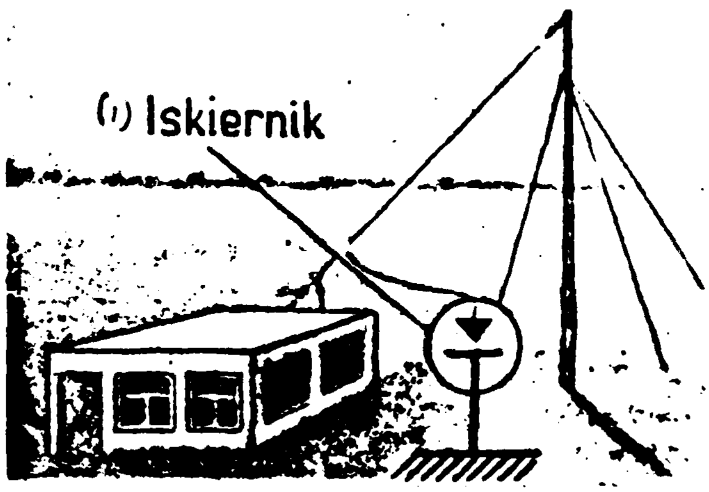
Screen cables (picture 10) or cables in metal pipes. It is more useful to use cables having a large shielding coefficient as well as a high electrical and mechanical strength. It is costly to put cables in metal pipes and also involves many difficulties.

Metal shields substantially decrease voltages between the cable and the earth and are most effective in protecting devices which are placed in permanent fortification devices.

Anti-static equipment. Anti-static equipment includes circuit-breakers (picture 11), protective spark gaps (picture 12), safety devices (picture 8) and fuse-links, line choking coils and transformers. These devices also protect against overvoltages occurring during nuclear explosions. They make it possible to disconnect equipment from the lines when an electromagnetic pulse occurs.



Picture 11. Transformers and circuit-breakers.
1. Transformer. 2. Excitation pulse. 3. Line. 4. Trip.



Picture 12. Protective spark gaps for safeguarding equipment connected to lines and antennas against overvoltage.
1. Spark gap.

The circuit-breaker opens and closes circuits. It has two positions in which it can open (break) or close the circuit without the participation of an external force (automatically).

The protective spark gap has two electrodes which are separated by a dielectric. A spark jumps between them if the difference in potential reaches a certain value.

The safety device is equipped with an apparatus located on a fuse-link which signals that the fuse-link has melted.

The spark gap safety device is a spark gap which is used to protect the low-intensity high-voltage circuit against an excessive increase in voltage.

The fuse-link safety device interrupts a path (where it is installed) by melting one of its elements. This occurs when the current passing through it exceeds a certain value within a certain period of time.

The fuse-element is the element in a safety device which contains a fuse-link that has to be changed after being activated and before being made operational again.

The line choking coil (coil) is connected to the network to protect equipment, devices, machinery or lines against overvoltage. These line choking coils diminish the attenuation of telecommunication lines. They weaken the steepness of the front in an overvoltage wave in heavy current lines and networks.

The transformer separates the apparatus from the line. It is a device which operates according to the principle of electromagnetic induction. It transforms the system of voltages and alternating currents into one or several systems of voltages and currents generally having different values but the same frequency.

Protective equipment Gloves, rubber boots, rubber carpets and so forth belong to this group.

In selecting protective devices, one has to consider that protective devices are spent in all circuits within the zone of a nuclear explosion when exposed to an electromagnetic pulse. This is why the protective devices should instantaneously and automatically make the circuits operational when the impact of the electromagnetic pulse passes.

Excitation voltages can propagate along long-distance heavy current and telecommunication lines, cable and overhead lines and over dozens of kilometers, thereby damaging equipment which is located outside of the explosion zone. Therefore, the input circuits of the equipment should always be protected. They should be protected even if no nuclear explosion is expected within the zone a given object is located in.

The resistance of equipment to overvoltages which are generated in lines during nuclear explosions largely depends on the proper operation of the line and constant supervision over the technical efficiency of protective devices. The following are extremely essential operational requirements: Testing the electric strength of line insulation and input circuits of equipment, detecting and removing the earthing of ducts, checking the efficiency of spark gaps, fuse-links and so forth).

* * *

The knowledge about physical and combat characteristics of nuclear weapons will make it possible to select appropriate methods and apply them when this kind of weapon is used as well as to promptly execute a combat operation.

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